Hierarchical Subsurface Imaging for Site Characterization Using Airborne and Vehicle Mounted Ground Penetrating Radar

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Abstract

In the last forty years, land mines have become one of the most serious threats to civilian populations in several parts of the world. To address this problem, humanitarian de-mining activities are being undertaken in many of the affected Countries. The de-mining process has, however, been fought with a number of difficulties since land mines and unexploded ordnance (UXO) are very difficult to detect and recover, and the contaminated areas are so large that current de-mining procedures are very inefficient. This paper proposes a new method to address the mine localization problem, based on a hierarchical localization and mapping of mine fields. This method would consist of a large-area aerial survey for the approximate localization and mapping of the minefields, and of map refinement by low-altitude aerial and ground surveys. The resulting map would then provide precise navigation directions within the contaminated areas to the de-mining teams. The sensing technology used in this method would combine Ground Penetrating Synthetic Aperture Radar (GP-SAR) and telerobotic technologies to achieve a high degree of automation and fast map generation capabilities. GP-SAR has been recently used with great success in mapping former artillery ranges in the United States. Telerobotic Technologies would be applied to the control and navigation of unmanned low-flying and roving robots, which would act as intelligent sensors. The paper presents a preliminary discussion of various aspects of the proposed hierarchical survey method, and discusses some of the advantages and difficulties of the approach.

1. Introduction

In the last forty years, land mines have clearly become one of the most serious threats to civilian populations in several parts of the world. Their uncontrolled and indiscriminate use in rural and suburban areas during civil and regional wars has impeded the recuperation and peacetime development of these areas, and has caused large numbers of deaths among the civilian population that out of necessity continues to live in the areas affected.

To address this problem, humanitarian de-mining activities are being undertaken in many of the countries affected. The de-mining process has, however, been fought with a number of difficulties. Land mines and unexploded ordnance (UXO) are very difficult to detect and recover, and the design of completely automatic de-mining systems is not feasible with today's technology. Furthermore, the size of the contaminated areas is so large that current de-mining procedures are neither time nor cost effective.

This paper summarizes several discussions among the authors on possible improvements to the de-mining process [1], and proposes a new method for increasing the mine clearance rate based on a hierarchical approach to the localization and mapping of mine fields. This method would include a large aerial survey for the approximate localization of minefields, the precise identification of minefield boundaries, and the mapping of exposed and buried explosive devices within each minefield. These maps would provide de-mining teams with navigation directions to and within the contaminated areas, thus significantly reducing the time for field operations and increasing the team's throughput and safety.

Recent significant results have been achieved in mapping former artillery ranges in the United States by using data produced by aircraft-mounted Ground Penetrating Synthetic Aperture Radar (GP-SAR). Synthetic Aperture Radar (SAR) is a remote sensing technology that has been extensively used for a variety of surface mapping applications. An emerging application of airborne SAR systems is subsurface imaging. Airborne ground penetrating SAR (GP-SAR) is a particularly fast and very cost-effective technology for subsurface imaging of large sites. A GP-SAR sensor can rapidly produce subsurface images of large areas in situations where the deployment of other ground-based sensors is either impossible (due to the terrain features) or time-consuming and costly. The recent results have shown the capability of radar systems to identify exposed and buried UXOs even in highly unfavorable Signal-to-Noise (S/N) environments, and to detect landmines of different sizes in a variety of terrain types. However, an aircraft-mounted GP-SAR system has neither the resolution necessary to identify small objects, nor the ability to provide precise localization data. This paper proposes a solution to these two limitations consisting of integrating the data of aircraft-mounted GP-SAR, with those of low flying and of vehicle-mounted GP-SAR's to resolve false positive identification and localization uncertainty of the suspect objects. This approach would overcome the problems affecting either airborne or ground-based GP-SAR surveys, when used independently. The first survey method lacks resolution and localization accuracy, whereas the second survey lacks coverage speed. The integration of airborne imagery with ground-based localization would solve both problems in a synergistic way by combining the sweeping capabilities of airborne systems with the pin-point localization accuracy of ground surveys.

1.1. Background

Humanitarian de-mining activities are being undertaken in many of the countries infested by landmines and UXO, however these efforts are not adequate to the size and complexity of the task. Since the areas contaminated by land mines and unexploded ordnances are typically very large, any substantial mine clearing efforts have necessarily to be carried out with an *assembly line* approach. In this approach, minefields are first identified, then mines in their interior are precisely mapped, and finally de-mining teams neutralize the detected mines. For de-mining organizations to have a chance of completing their work within a reasonable number of years, a significant increase in de-mining efficiency over current methods has to be achieved.

More than 65 countries in the world are affected to varying degrees by land mines. There are about 120 millions of mines world wide, and this number is growing at a rate of 2 millions a year. Only 100K land mines are removed every year, at a cost, in 1993, of $67 million. According to the International Committee Red Cross report, mines and other unexploded ordnance kill 500 - 800 and maim 2000 people each month, mainly innocent civilians. Severe landmine problems exist in all Continents. In Europe, affected countries include Croatia, Bosnia and Herzegovina (about 1.7 million buried mines), Yugoslavia (5-7 million mines); in the Middle East: Egypt, Kuwait, Iraq and Iran; in Africa: Angola, Somalia, Sudan, Ethiopia, Mozambique, and Rwanda; in Asia Afghanistan, Cambodia, Laos, Chechnya, Kashmir; in Central America: Honduras and El Salvador; and in South America the Falkland Islands.

Land mines and UXOs are very difficult to detect and recover, and the design of completely automatic de-mining systems is not feasible with today’s technology. This limitation is particularly true in regard to the neutralization of mines. Recent developments in sensor technology have, however, the potential for making a significant impact in the operational efficiency of minefield identification and mapping. In fact, experiments performed under controlled conditions have shown that the efficiency of standard de-mining procedures can be significantly improved using new sensors and new forms of sensor data fusion.

The automatic identification of minefields and of single mines using sensor systems is a very challenging problem, made even more difficult by a number of unpredictable environmental factors. Minefields may be littered with metal debris, unexploded shells, rockets or mortar rounds, often lying just below the surface. This makes the use of metal detectors more difficult, causing many false positive readings. In some climates, thick shrubs may have grown and covered minefields placed in previously cultivated fields and rice paddies. In open country or riverbeds, storms or floods may have carried mines some distance from their original locations or have buried them under layers of soil and debris. Mines placed in or close to buildings may be lying deep under fallen rubble, with yet more mines laid on top. Some mines may have been set up using booby traps, detonating (for example) when something of apparent value is picked up. Irrigation canals with mines on the banks or on the bottom may have been filled in with dirt during ground clearing by bulldozers, thus burying the mines under a layer of soil. In climates where the ground freezes during winter, some mines may explode from the pressure produced by expanding ice, while others will lock up and fail to detonate even when stepped on. These will remain dormant until spring, when the ground becomes soft again. Mines may have been in place for 5 or more years, and consequently may have become corroded, waterlogged, impregnated with mud or dirt, and will therefore behave quite unpredictably. UXOs are likely to have less unpredictable behavior than mines, but present detection difficulties similar to landmines, since they are usually encountered buried deeper than mines, and can be covered by debris and vegetation.

Given the above scenarios, a sensor-based approach to land mine and UXO detection that relies solely on data provided by independent sensors handled separately will not have the levels of operational reliability necessary to gain the confidence of the de-mining community.

Based on the considerations outlined above, the accurate localization of minefield borders and of mines has been identified [9] as one of the key needs of de-mining. Current de-mining practices dictate that each minefield be surrounded by a very broad safety zone to account for the unknown true dimensions of the field. Screening this safety zone increases the operation cost tremendously, since the de-miner must behave with the same caution and speed as if he were in the real mine field. The same considerations holds for screening *low density* minefields, where mines are laid out every 100 meters or so. Here too, the efficiency of a de-mining operation could be improved significantly if the de-miner had a map of suspected mine locations. False alarms are not considered a serious problem in this context.

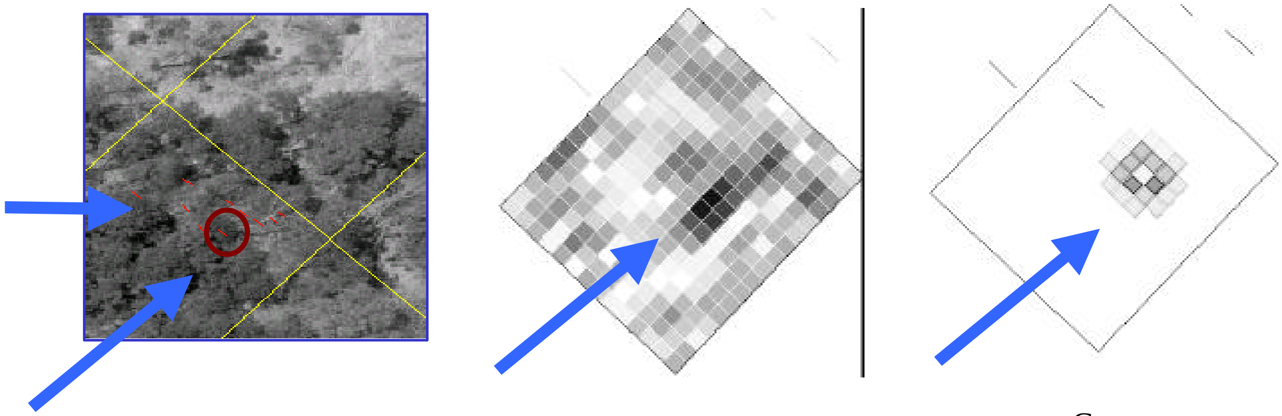
The capability of identifying those areas that are truly contaminated among the millions of hectares that are suspected of contamination is, therefore, a major objective of any automation aid to de-mining. This need suggests the development of tools that would allow broad and efficient searches for mines, while providing successive refinements of the estimates of their locations. In the broader framework that underlies this paper, large-scale aerial surveys would identify the minefields, possibly extending over several square kilometers, by detecting the sensor readings generated by the mines. Subsequently, the minefields would be further scanned to map their boundaries and the mine locations. Finally, a de-mining team would use the map of the minefield to reach each suspect location. This approach would permit large savings of time and provide the de-mining teams with a steadier flow of recoveries, unlikely current manual techniques which sometimes let several days elapse between mine discoveries.

A similar approach is also applicable to the search and detection of UXOs. These devices are more likely to be found in isolation or in small clusters. Since cluster bombs deploy explosive devices very similar to land mines, they create the equivalent of mine fields with exposed or partially buried so-called sub-munitions. For these reasons, and in spite of the significant differences between UXOs and land mines, any method developed to detect land mines should also be applicable to UXOs, and must be designed accordingly. In particular, high resolution aerial surveys of the type proposed here can be effective for both contamination types.

1.2. Past Work

A new approach to demining using large-scale aerial surveys is currently being developed in the United States [1]. It focusses on the use of a manned aircraft-based GP-SAR system flying at an altitude of approximately 1000 m. This method is scheduled for use in a real de-mining operation during the 1998 summer to clear Buckley Field [2], a former artillery range near the city of Denver. There are, however no current plans to develop techniques for the detailed examination of a single mine field.

The high-elevation aerial survey has been carried out by a team consisting of researchers from Stanford Research Institute (SRI) and the Jet Propulsion Laboratory (JPL), using SRI GP-SAR. Previous attempts of using airborne SAR systems for detection of unexploded ordnances (UXOs) have been generally unsuccessful due to:



A B C

Figure 0: Example of UXO detection using GP-SAR

a) Very low signal-to-clutter ratio for most of the application sites, and

b) Relative small size of the targets with respect to SAR resolution, resulting in sub-pixel targets.

In 1995, JPL and the U.S. Army Corps of Engineers, Huntsville (USACEH) conducted the largest ever survey (covering more than 19,000 acres) over former Camp Croft, SC, using SRI's airborne ground penetrating SAR. Camp Croft represented a major technical challenge for the deployment of airborne SAR due to large variations in ground features and heavy vegetation. Using novel image processing techniques, the JPL team succeeded for the first time in detecting small UXOs (60 mm mortar shells) at depth of up to 25 cm. The JPL results were initially validated against ground truth provided by USACEH (in the form of reports of UXOs found by walkthroughs). In a follow-up experiment, an analysis of a small area (100 acres) was performed. The subsequent walkthrough survey of this area, executed by USACEH, validated the results of the analysis. The terrain characteristics of Camp Croft also provided a good validation of the technology. The soil is rich in clay and sand, with a thin active soil layer (<50cm) of decomposed leaves and humus. The terrain varies from gentle to fairly rugged, with wall slopes of up to 45^{o} , traversed by streams and valleys. The vegetation consists of 40-yr old tree growth, with forest floor well populated by fallen branches, small shrubs, and rock piles [3]. An example of subsurface UXO detection is shown in Figure 1.

Figure 1-A is an aerial photo of an area of heavy vegetation in Camp Croft. The picture indicates also the ground truth position of a few mortar shells (60 mm) (dark segments barely visible), and the location of a shell at a depth of 6 in. below the surface, identified by the processing algorithm (dark circle). Figure 1-B is the radar image (VV Magnitude) of the sub-area containing the UXO. Finally, Figure 1-C is the signature of the UXO resulting from the application of image processing algorithms. This picture shows that, although several mortar shells are not identified by the algorithm, some disturbance is detected, and the contaminated area is identified. Furthermore, Figure 1-C shows the uncertainty with which UXOs can be identified. Since each pixel corresponds approximately to 1 square meter, it follows that this aerial survey can identify disturbances within a circle of uncertainty of 20 m diameter.

To show the applicability of these techniques to landmine targets, test surveys were carried out in the Yuma Proving Ground (YPG), AZ. This site has a training minefield with mines deployed in a controlled pattern and at known depth, as shown in the following figure. The terrain type and the vegetation are very favorable to aerial GPR surveys, since Yuma is in the Arizona desert, with little terrain humidity and sparse vegetation. Nevertheless, the results support the validity of this approach, as shown in the pictures in Figure 2.

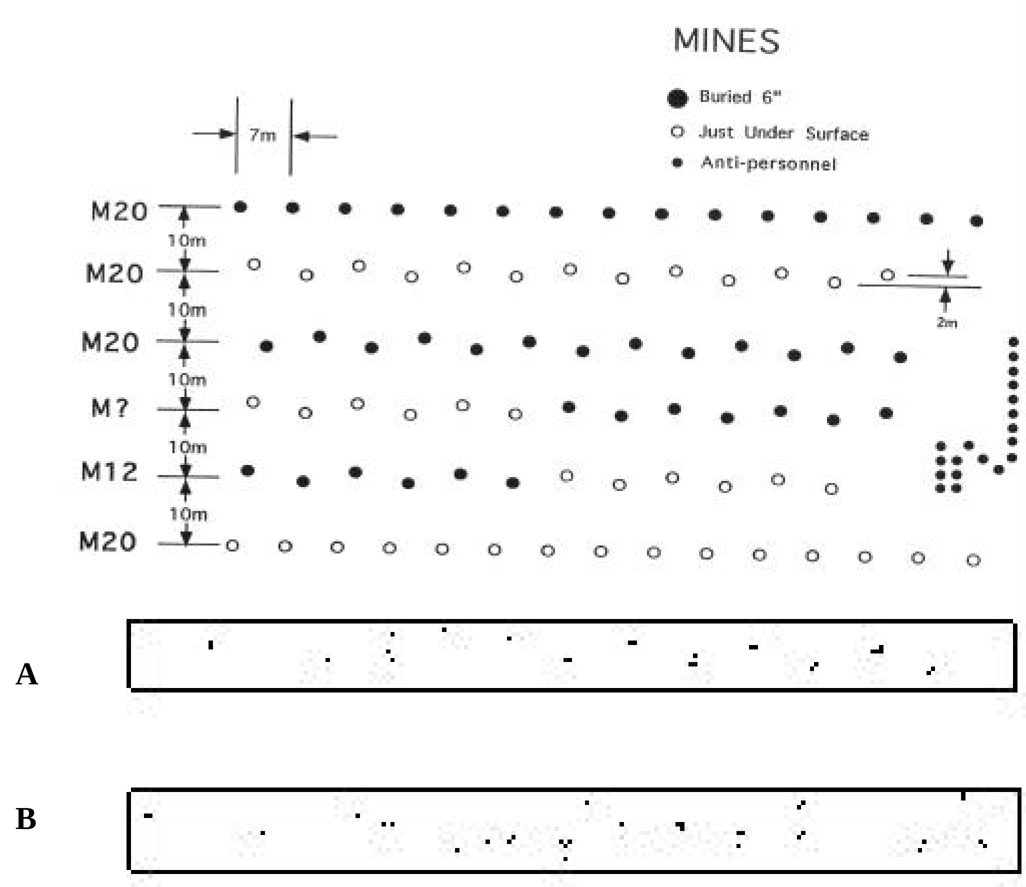


Figure 2 : Results of GP-SAR analysis at Yuma Proving Ground

Figure 2-A shows the signature of the M20 mines at a depth of 6 inches below surface (3rd row from top). Figure 2-B shows the signature of the M20 mines just below the surface (6th row from top). As can be seen from the results, the method proved to be very effective in identifying the contaminated areas [4].

As we discussed earlier, however, large scale de-mining requires highly automated procedures to achieve reasonable clearance rates. For example, the algorithms currently used at JPL can process up to 500 radar magnitude pictures of the former Buckley Bombing range. This corresponds to approximately 200 acres a day of survey, out of the 57,000 acres of the site. Therefore, this bombing range alone will require two years of continuous processing, just to identify the possible contaminated areas.

To coordinate the data acquisition and processing on several control stations, new powerful operator interfaces should be developed. Advanced operator interfaces have been an active area of research for the last several decades. A complete range of underlying component technologies is available, such as graphical simulations, stereo and mono displays, graphical preview displays, local-area and internet-based data displays. In addition, a number of complete operator interfaces for different applications have been developed and demonstrated at various laboratories. In particular, the Advanced Teleoperation Interfaces [7] demonstrated the capabilities of a complex human-machine interaction involving real-time video, graphical simulations integrated with video display, multi-dimensional data display. Recently, operator interfaces are taking advantage of the capabilities offered by Internet. Most notably is the Web Interface for TeleScience [8], allowing automatic data transfer and operation command using Internet-based browsers, in a completely distributed and platform independent mode.

2. Technical Considerations

In light of the considerations summarized in the previous sections, this paper addresses the development of a possible improvement to the JPL-SRI methodology for the preparation of detailed surveys of small geographical areas, roughly corresponding to a single minefield. We assume that previous large scale aerial surveys or historical and oral data provide information on the approximate location of the potential minefields. Additionally, the proposed method does not address the final recovery and neutralization of the explosive devices, which is to be carried out using standard procedures.

We propose to extend the capabilities of high-altitude GPR-SAR by employing a low flying platform, such as a unmanned helicopter, and a vehicle mounted GP-SAR, to increase the target detection sensitivity and reduce the uncertainty in target localization. The data processing algorithm lends itself very well to these extensions, since it processes radar amplitude images by successively identifying the local maxima corresponding to possible disturbances. This process can be enhanced by fusing images taken by radars with different characteristics. Successive improvements may consider the integration of images taken by different radars, such as IR cameras, however in this paper we consider radar images only.

2.1 Proposed Scenario

In developing the concept of the proposed hierarchical GP-SAR imaging system, we assume a reference scenario as shown in Figure 3. In the first phase of a demining operation, a manned high-altitude GP-SAR survey of a large contaminated area will be carried out. Since this aerial survey cannot provide accurate target identification and only approximate boundaries of the potential minefields, its information will be used to mark suspect areas for more detailed surveys.

In the second phase, an unmanned airborne survey of the marked areas will be performed. An unmanned aerial vehicle of appropriate payload and mission duration will be employed. The vehicle will be operated using a combination of remote control and onboard flight control capability (including Global Positioning System *GPS* and Inertial Navigation System *INS*), allowing it to conduct precise, low-altitude flights and therefore providing more accuratel target discrimination and localization data.

In the third phase, a small, unmanned ground vehicle will be deployed. This vehicle, equipped for all-terrain traversals, will also be using a combination of remote control and onboard obstacle avoidance and navigation capabilities. It will be guided to the specific sites that have already been identified as having suspect targets, based on the previous surveys. It will be instrumented with self-localization capabilities using GPS and INS sensors, and with detection devices to allow it to perform on-site, close-to-target, inspection and localization. In this paper, we will consider only a vehicle-mounted GP-SAR, as the on-board instrumentation.

In the final, manned phase of the reference scenario, manned de-mining teams will proceed to the sites where potential mines and/or UXOs have been identified. This will substantially increase the safety and speed of operation of the team, since they will be able to proceed directly to suspect sites to perform the final target identification and deactivation.

Currently, the exploration of mine fields consists almost exclusively of Phase IV survey (see Fig.1) involving hand-held devices such as metal detectors. Inherently, this leads to a rather limited speed and performance. The results of current GP-SAR surveys are not particularly useful to the demining teams, since they do not provide the resolution needed by the de-mining teams. Filling this gap between manned airborne large-scale survey (Phase I), and the burdensome, dangerous, and little effective exploration using metal detectors (Phase IV) is the main objective of the method proposed in this paper.

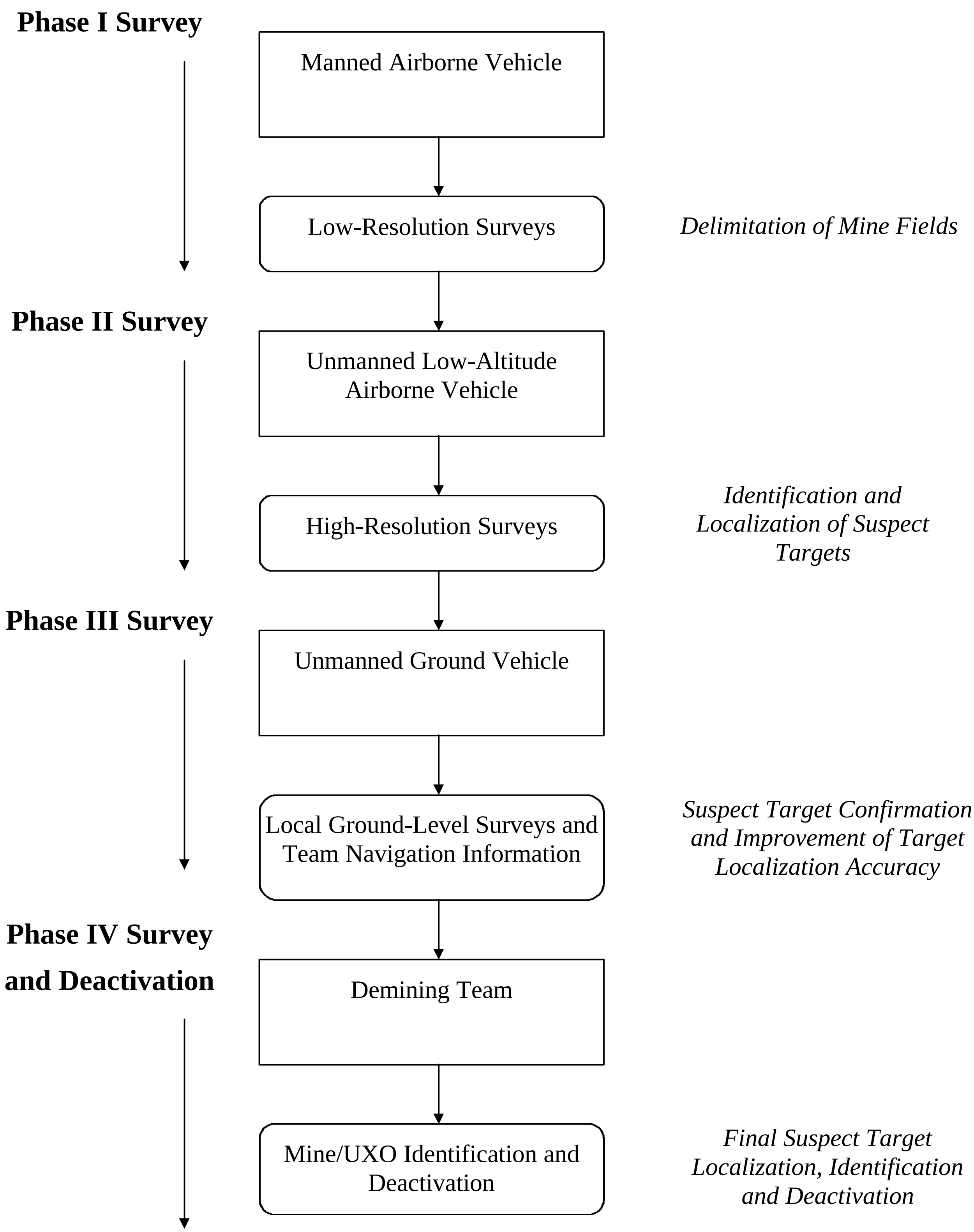


Figure 3 : Proposed survey sequence.

2.2. The Low-Altitude Aerial Sensor

To allow the generation of high-resolution surveys of potentially contaminated areas, neither manned aerial flights nor ground-based surveys are appropriate alternatives.

Manned aircraft are very expensive in terms of the initial acquisition costs, maintenance and operation costs, and crew training and salaries. This results in very high costs per mission flown. An additional limitation is caused by the fact that aircraft and crew safety considerations require manned airborne surveys to be conducted at typical heights of several hundred to a 1000 m or higher, limiting the resolution of the data being acquired.

An approach overcoming some of the limitations of manned, high-altitude airborne surveys would consist of developing unmanned aerial platforms for the acquisition of high-resolution ground imagery. Unmanned teleoperated aerial vehicles for civilian applications are available at a fraction of the cost of manned aircraft, and are correspondingly cheaper to maintain and operate. Consequently, the cost per mission is reduced in a very significant manner, while no human lives are endangered in potentially dangerous missions.

Of the possible types of unmanned aerial platforms available, tele-operated helicopters provide one of the most interesting alternatives. Unmanned helicopters are highly maneuverable and can operate in very uneven terrain at reasonable speeds. Additionally, there are commercially available systems that can carry the required sensor and telemetry payloads. Furthermore, there is already a significant body of experience in hybrid operation of helicopters, where GPS and INS systems are used for in-flight trajectory execution or in-place hovering, while the human operator handles the flight phases that are more difficult to automate, namely take-off and landing.

The ideal platform for this sensing phase is a teleoperated helicopter with the following characteristics: payload of approximately 25 - 30 kg, 2-4 cylinder air cooled gas-engine, 2-blade main-rotor with stabilizer system, 2-blade tail-rotor with electronic stabilizer, radio controlled with high speed servos for main-rotor and tail-rotor, engine and rotor-speed governor, and electronic stabilizers (gyroscope) for main-rotor and tail-rotor. Operator training and operator interface are well know difficulties in the remote control of unmanned helicopter, and therefore will require a significant development effort to permit the operation of this system by non-specialized personnel.

Airborne GP-SAR's are not commercially available, and only a handful of research laboratory world-wide can claim some expertise in this area. However, the quality and the possibility implicit in the results presented by the JPL-SRI team would justify the investment necessary to develop the new GP-SAR's needed by this project. Furthermore, several companies are actively working in making ground penetrating radar capable of low-altitude airborne operation [5]. In particular, current active R&D efforts are focusing on the development of new antennas, the use of new modulation techniques, and on reducing the total weight and cost of the system. In particular, the main features of the new airborne GP-SAR under study will be as follows. Total weight of 10 Kg, compatible with the payload of a small teleoperated helicopter. Use of Micro Power Impulse modulation, for total power and size reduction. Application of new perfectly matched antennas, for improved bandwidth and operation up to 20 m of elevation.

2.3. The Vehicle-Mounted Sensor

To complement the results of the aerial surveys, a ground inspection is necessary. Currently, several system, either laboratory prototypes or commercial products, are available for this purpose, however none has been integrated in a larger, coordinated survey system. Then, an economic ground vehicle could be acquired and equipped with a sensor system complementary to the aerial sensors, to develop the coordinated survey techniques that will satisfy the proposed scenario.

Wheeled teleoperated vehicles are currently available commercially, or can be inexpensively duplicated from laboratory prototypes[12]. Commercial products can be used, such as the outdoor vehicle developed by Real World Interface (RWI) of New Hampshire, USA [10]. This device is an example of mobile platform with all terrain capabilities, equipped with Linux-based computer, infrared and ultrasound sensors for navigation, and wireless Ethernet link to a remote control station.

The software comes with planning and navigation aides that provide basic teleoperated and autonomous capabilities. RWI competitor, Nomadic Technologies [11] does not have an outdoor product. A vehicle of this class could be purchased and retrofit to better suite the needs of de-mining tests. The range of the standard communication link should be increased, and the body should be reinforced to withstand debris from nearby explosions.

A new sensor system should be developed consisting primarily of a vehicle-based GPR-SAR GPR is one of the key sensors for the detection of buried mines. The specialization of radar technology and processing techniques to identify mine echo is currently under way. However the achievement of real time or near real time processing embedded into the GPR system is a crucial objective in order to make possible the application of advanced identification techniques. Based on available GPR sensors and processing techniques a processing system embedded to the GPR acquisition sub-system should feature:

- monostatic and bistatic measurements, using an array of wide band antennas (band is in the order of 100% of “central” frequency),
- multifrequency; using the antennas in various frequency bands;
- polarimetric capabilities;
- 3D soil tomography data processing techniques.

The embedded processing hardware and software should also be developed, using a parallel computing architecture, to achieve the following objectives:

- acquisition and storage of raw data from the antenna array,
- pre-filtering and dynamic equalization;
- ground characteristic estimation;
- additional 3D processing, such as pattern recognition, and identification techniques.

The estimated requirements for the embedded system are of the order of 150-200 MFlops of computing power, data memory no less than 4 MB, and 1 MB/sec. Data Transfer Rate.

The ground sensor system should also include a commercial metal detection system, whose data will be fused in real time with the GPR images, thus providing the precise location and metal content of a buried object. The local map developed by these sensors will be integrated with the global map generated by the aerial survey, to replace the uncertainty areas in the map, with the precise location of each object detected.

The vehicle navigation system should be enhanced by a stereo camera system, to provide distance measurement, depth perception and identification of exposed devices. Also in this case, a commercial stereo camera will be purchased, and standard stereo vision algorithms will be adapted to the specific requirements of a de-mining operation.

2.3.1 The Ultrasonic Probe

2.4. Multi-Sensor Fusion and Map Generation

The integration of the geographical information with the images from two aerial platforms will allow the development of the precise map of the contaminated areas.

The airborne and the ground GP-SAR systems will acquire the sensor data. In order to provide a first indicator to the ground team, the airborne sensor system data will be fused together with a geographical information database. The output of this process will be a map indicating the probability of presence of mines or UXO’s and uncertainty of localization area. This map is produced off-line after the survey of the suspected field an displayed to the operator. A further development in the project would be to provide this map in real-time to the user who could control the flight to enhance the data. In order to produce the map, the position of the air vehicle as provided by a DGPS (Differential GPS) is integrated. Images of the suspected areas are included to the display as a help to the operator and the de-miner. The ground vehicle uses this map as an input to navigate to the suspected zones directly. A considerable amount of time would thus be saved thanks to the airborne system and the resulting map.

The techniques for fusing sensor data are being developed for several years. In the approach proposed here, each sensor would provide a signal which, after proper processing, is first transformed into a probability of mine or UXO presence. All the sensors probabilities will be located on the geographical map. The probabilities will then be fused using for example a bayesian technique (the actual approach will be selected during the project). This will eventually provide a unique distribution of the probability of AP mine or UXO presence.

The map will also include navigation indications to the ground vehicle, for example by producing the shortest path to reach the detected areas, or the safest path, or by including some danger indications for example when booby traps are suspected because of the mine layout. The images collected from the air vehicle will be included to give proper indications to the ground team. In case several ground vehicles or de-mining teams are available, the system can also be used for dividing the field in an optimal way between the different teams. Motion planning algorithms are well known in the literature, and the partners have good experience of developing and implementing such systems. Their application to the de-mining context will be achieved.

2.5. Control and Processing Station

Two major objectives should be pursued to design the high-power control station for vehcile control and data processing required by the proposed survey scenario:

- The deployment and use of an multi-processor platform, for fast analysis and fusion of data from the aerial sensor system, and
- The development of a control and command station for the teleoperation of the aerial and ground vehicles.

Since these activities, as described in the proposed scenario, will not occur at the same time, both objectives can be satisfied by the development of a single advanced operator interface, with graphical and video capabilities for planning and monitoring the teleoperation activities, and for supporting intensive data processing.

The approach proposed here would be supported by a novel, integrated operator interface that will allow operators to access and fuse all the information relevant to a de-mining missions in a single graphical display. The interface will have intelligent advisory capabilities that will automatically notify the operator of critical relations among the mission variables. The interface will automatically fuse this information in a multi-dimensional graphical display that will support graphical simulation of forecasted data, visualization and update of data collected during the mission, and automatic data fusion and analysis. A graphical framework will be used to integrate the data returned by the aerial and ground sensors and by the de-mining teams, regarding environmental parameters, radar and magnetometer readings, and location and type of mines and other obstacles. These data will also be made available from the interface of entry to other operators involved in the mission, and the graphical representations will change accordingly. Live images from the vehicles will be displayed in the operator interface and integrated with suitable graphical enhancements, to facilitate the data analysis and the control of the aerial sensor platform.

The proposed control station would include the following features:

- Data fusion algorithms and Web-based data visualization, and vehicle teleoperation.
- Transparent and intelligent access to distributed information sources.
- Operator training and mission control in typical simulated and training scenarios.

In particular, the operator interface will have the following roles:

- Display the helicopter fly status and transmit the teleoperation commands.

- Display of ground vehicle status and transmit the teleoperation commands.
- Receive the data from the aerial sensor platform and generate the mine field map.
- Interactively display to the user the information relative to each mine on the map.
- Maintain the database of suspect contaminated areas, and overlay them on the map.

The computing architecture needed for the intensive data processing and communication required by the radar image analysis should also be investigated.

2.6. Testing and Calibration

For an application such as mine and UXO clearance, it is not sufficient to verify that the design satisfies the system requirement, but it is also necessary to build confidence in the users about the reliability and trustworthiness of the equipment. A single failure can have terrible consequences on the people involved and on the technology itself, independently of whether the accident was caused by a situation outside the official requirements.

Therefore, testing takes the form of a validation plan carried out by the technology developers and by the users, to gradually cover as many real situations as possible, within and without the design specifications. The proposed survey method should be designed with enough smart to identify new situations and indicate to the operator the confidence of its measurements. Testing and calibration will be carried out in parallel, since terrain and vegetation types will affect the operation results, and it is not imaginable to have a laboratory calibration that will fit all situations. By necessity, the sensing algorithms should be calibrated in the field, but a small number of terrain and vegetation models should be pre-stored, to cover the most common situations. A few key terrain compositions and conduct should be identified as validation experiments. It will be necessary to build a sufficiently large data base of different terrain composition and vegetation types, to would allow a statistical analysis of the data and the determination of the "a priori" confidence in the measurements taken in a new environment. This measure will determine the need for a new calibration of the sensing algorithms when used in a new environment.

2.7 Advocacy and Users: the Role of NGO

3. Conclusion

This paper summarizes some of the on-going discussions among the authors on new and more efficient methods to improve the speed of land-mine and UXO clearance operations. The method addresses the mine localization problem, and is based on a hierarchical acquisition and processing of minefield data. This method would include a large-area aerial survey for the approximate localization and mapping of the minefields, and of map refinement by using low-altitude aerial and ground surveys. The sensing technology proposed for this method would be based on Ground Penetrating Synthetic Aperture Radar (GP-SAR) supported by unmanned flying and roving vehicles, to achieve a high degree of automation and fast map generation capabilities. The paper discusses in some detail the technical trade-offs of the proposed method, and the requirements of a few critical sub-systems. The authors are aggressively pursuing appropriate funding sources, to start the development and test of the proposed method.

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